ANALYSIS OF TEST DATA ON THE SIMPLEX

STRAPDOWN NAVIGATION SYSTEM

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1.0 INTRODUCTION

This report gives the results of a study of test data taken on the simplex strapdown navigation system. This system (see Figure 1) consists of the following components:

- Strapdown Platform - The strapdown platform contains three Sperry model ASLG-15 Ring Laser Gyros and three Kearfott Model 2401 Accelerometers. The gyros and accelerometers are arranged so the instruments input axis are parallel to orthogonal triad axes. The arrangement of these axes is such, that when the IMU is level, the angle between the local vertical and each of the axes is equal (see Figure 2). The IMU provides angular rate and linear acceleration data.

- Altimeter - The altimeter is a Rosemount Model 1241A Barometric Altitude Transducer. The altimeter provides altitude data for vertical position and velocity computations.

- Digital Computer - The digital computer is an IBM SUMC (Space Ultra-reliable Modular Computer) Model HTDU (Hybrid Technology Demonstration Unit). The digital computer and its associated software interface with the other system components to determine the system's attitude, position and velocity. The computer was also used to determine the constant biases on the accelerometers and gyros. The computer test set provides the means by which the operator can control the digital computer; it also provides displays for determining real time system performance.

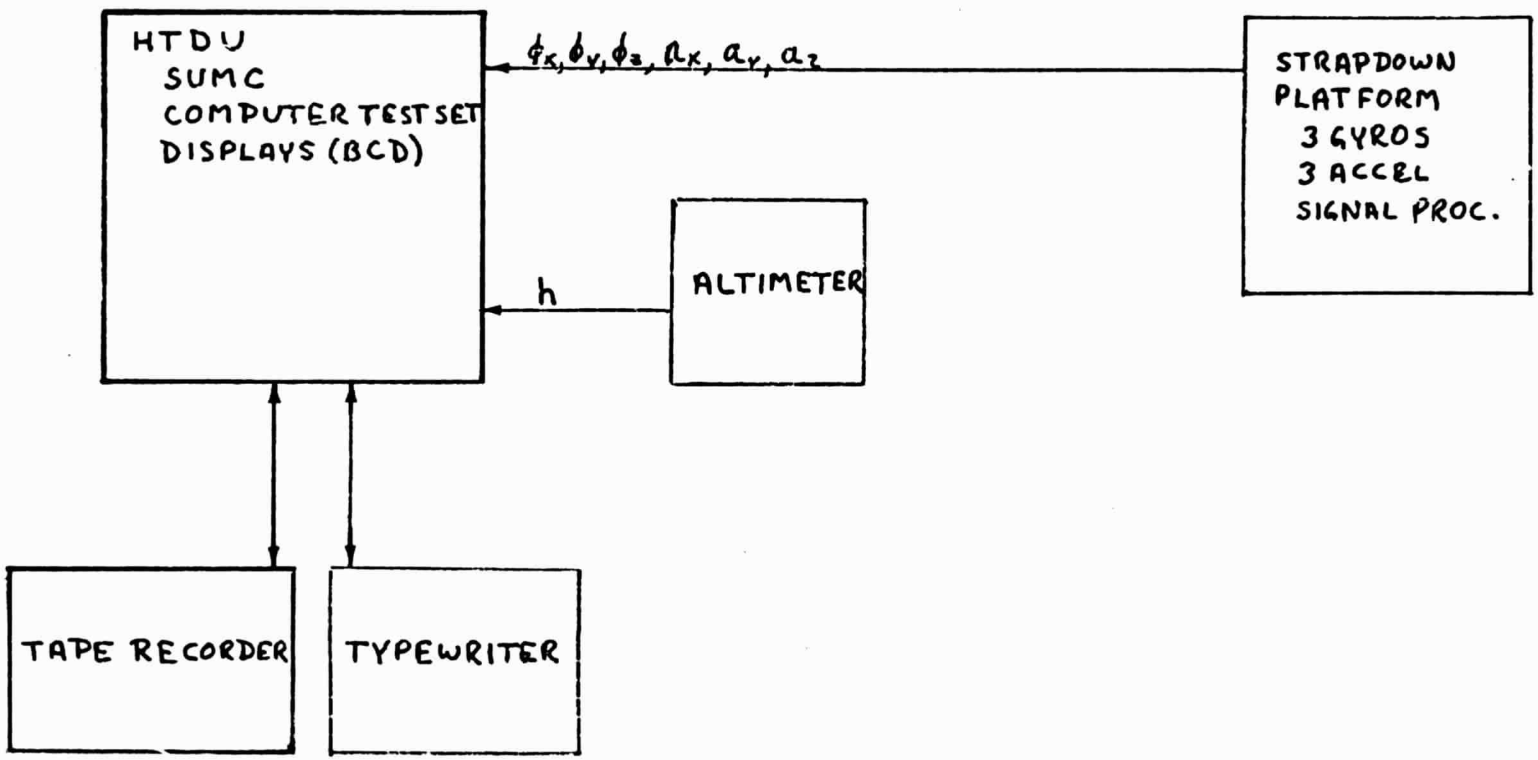


Fig 1
Strapdown Navigation System

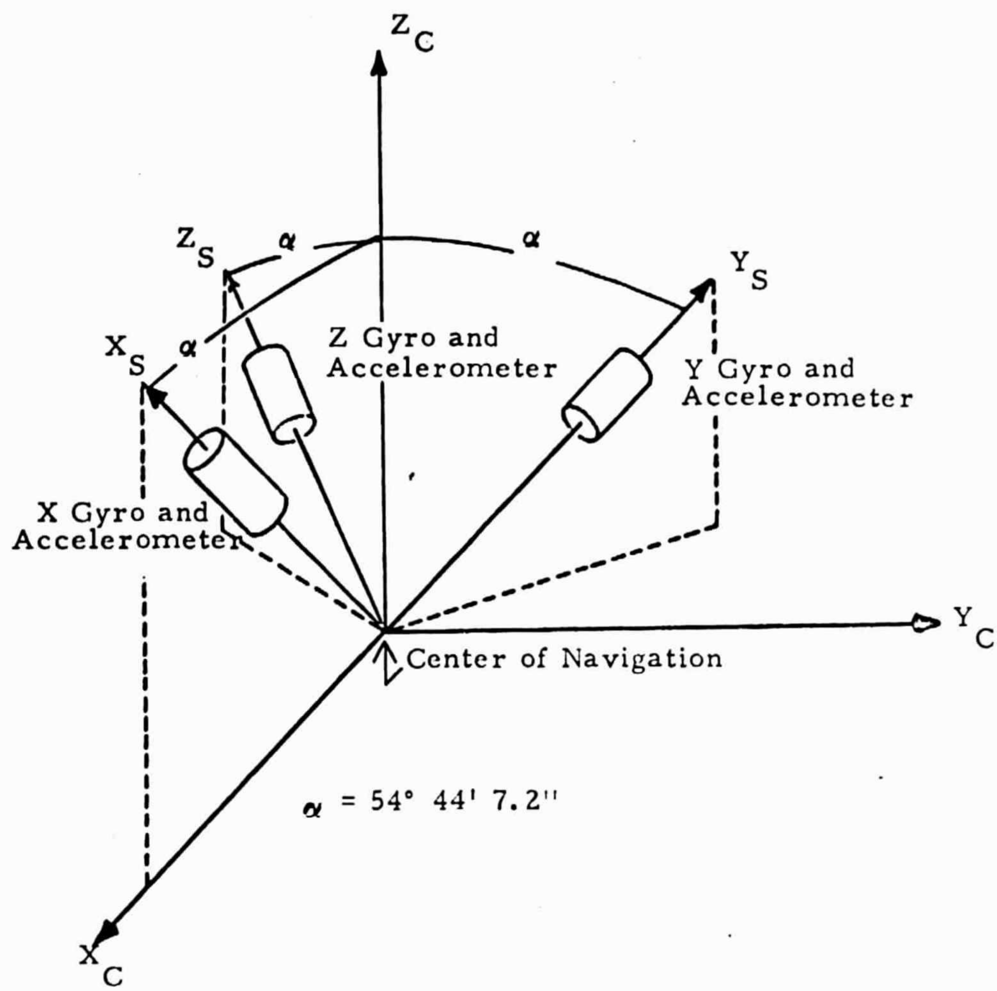


FIGURE 2

IMU SENSOR COORDINATE SYSTEM

- Tape Recorder - The tape recorder provides the means ofloading and storing the computer software and of recording the system's test data.

- Typewriter - The tele-typewriter provides real time means of controlling the program operation and memory alterations. It also provides limited real time hard copy data.

- Power Sources - The computer, tape recorder and typewriter require 110v, 60Hz A.C. power; this power was provided by varioous sources (ground power, A.C. generator, mobile power units, and inverted helicopter power). The IMU and the signal processors require 28v, D.C. power; this power was provided by various sources (ground power or A.C. generator power through a D.C. power supply, and 28v, D.C. batteries).

Data from system test has been studied in order to isolate error sources which may have caused degradation of the system's accuracy. This report contains recommendations of changes to the system test procedures, or computer software to limit system errors.

2.0 SYSTEM TESTS

The simplex strapdown navigation system was tested in three separate environments. The first tests were performed in thelab at MSFC's Astrionics Laboratory. These tests were run with the IMU mounted on a rate table. The following type tests were made in the lab:

- Static Tests (Full System Active) - These tests were run by taking an optical alignment; calibrating the gyro and accelerometer biases with the calibration program, then navigating with the full navigation program using the gyro, accelerometer and altimeter inputs.

- Static Tests (Strapdown Inactive)- These tests were run the same as the static tests (full system active) except the strapdown reference was not updated (i.e., the local reference of the accelerometer input axes was held constant).

- Static Tests (Position Computation Inactive) - These tests were run the same as the static tests (full system active) except the position computations were bypassed to prevent position error build-up from causing earth rate compensation errors.

- Rate Table Rotation Tests - These tests were run the same as the static tests except once the system was in the navigation mode the IMU was rotated about two of the three axes of the rate table, then back to the known reference.

The next series of tests were run in Astrionics Laboratory's mobile test unit at MSFC. The IMU was mounted on table fixed to vehicle frame. Other system components were shock mounted. The following tests were made in the mobile test unit:

- Static Test (Full System Active) - These tests were run the same as in the lab, except a new optical alignment was taken prior to entering the navigation mode.

- Static Test (Strapdown Inactive) - These tests were run the same as in the lab, except a new optical alignment was taken prior to entering the navigation mode.

- Mobile Tests - In these tests, the alignment and calibration was done the same as the static tests; when the system was in the navigation mode the mobile test unit was driven over a known course and stopped at known bench marks.

The next series of test were made in a Sikorsky SH-3A helicopter at Langley Research Center and at Wallopo Station Test Range. The IMU was mounted ona table fixed to the helicopter, other system components were shock mounted. The following tests were made in the helicopter:

- Static Tests (Full System Active) - These tests were run the same as the static tests made in the Mobile test unit. Static tests were made both in the hangar and on the flight line.

- Flight Tests - In these tests, the alignment and calibration was done the same as the static tests; when the system was in the navigation mode, the helicopter was flown to known bench marks or was tracked by radar. The following flight tests were made:
    1. Checkout flight at Langley
    2. North-south flight at Wallops
    3. East-west flight at Wallops
    4. Northeast-southwest flight at Wallops
    5. Consistent altitude circles and descending spirals, at Wallops
    6. Closed Course at Wallops

  All the flights at Wallops had radar tracking.

3.0 TEST DATA

Numerous forms of data from the various tests was analyzed to try to isolate the system's error sources. The following is a list of the types of data analyses:

- Typewriter Output - In the navigation mode, the typewriter standard output gave six program parameters (time, latitude, longitude, altitude, heading and total velocity). The frequency of these outputs was one group of data per minute.

In addition, typewriter data of calibration parameters was also analyzed. Typewriter data was available for all system tests. Notes were also written on the typewriter outputs to indicate such things as bench mark, first motion, take-off, etc.

- Tape Recorder Data - The parameters listed in Table 12.1 of the Strapdown Navigation program Requirements Document were recorded by the tape recorder for all tests; however, these tapes were not reduced to hard copy except for certain tests, or when problems occurred and further data was desired. Tape recorder data of all these parameters was not available for analysis of any of the tests made at Langley or Wallops.

- Bench Marks - In certain tests, the known latitudes and longitudes of bench marks were used to determine system performance.

- Real Time Radar Plots - Automatic plots from the radar data of the vehicle position and velocity were made during each flight at Wallops Station. Typewriter data from the program was manually plotted on the radar plots.

- Hand Plotted Data - Hand plots of velocity error, latitude error and longitude error were made for many of the tests run in the lab, mobile test unit and helicopter.

- Plots and Hard Copy of Radar vs. Tape Recorder - The position and velocity data from the radar vs. tape recorder data was reduced. This post-flight data was in both plotted and hard copy form and was available for the flights made at Wallops.

- Logs, Notes, Displays and Real Time Experience - In addition to the above data, logs and notes taken during each flight and the real time experiences as related to the display were reviewed.

4.0 OBSERVATIONS AND CONCLUSIONS

In reviewing and analyzing the various form of test data, certain conclusions can be drawn. However, due to the fact that most of the test data only shows the effect of system errors on navigation and similar effects can be caused by a number of sources, it is almost impossible to isolate all the errors as being due to any particular set of system errors.

The following are some of the observations made after reviewing and analyzing the test data and conclusions made about these observations.

The test data taken on static test with the full system active and static test with the strapdown inactive was compared. The test in which the full system was active had much larger errors than the same test with the strapdown inactive. An example of this is the comparison of two tests run on September 19. 1974. In the run in which the strapdown was inactive the longitude and latitude errors at the end of an hour were +.001 and -.003, respectively (Figures 3 and 4); the maximum velocity error over the same time period was .16 m/s (Figure 5). A similar run with the strapdown active had a maximum longitude error of -.05 (Figure 6) and a latitude error of .025 (Figure 7); the maximum velocity error reached about 5 m/s (see Figure 8). The errors in the case where the strapdown was inactive can be isolated as being due to accelerometer bias instability, accelerometer noise, level misalignment or level stability. A similar test run in the mobile test unit indicated that the level stability was not as good as in the lab. It can be concluded that larger errors seen when the strapdown was active must be due to gyro bias stability or gyro noise. The rapid degradation of the position and velocity at 2500 seconds in the full system active case would indicate a rapid change in the bias on one or more gyros or a burst of gyro noise. Real time observation of the displays indicated a change in the strapdown altitude. It was not isolated as to which gyro was responsible for the strapdown change.

DATE: 9-19-74
TEST: STATIC NAV TEST; STRAPDOWN INACTIVE, IN LAB.
DATA: LONGITUDE ERROR VS TIME

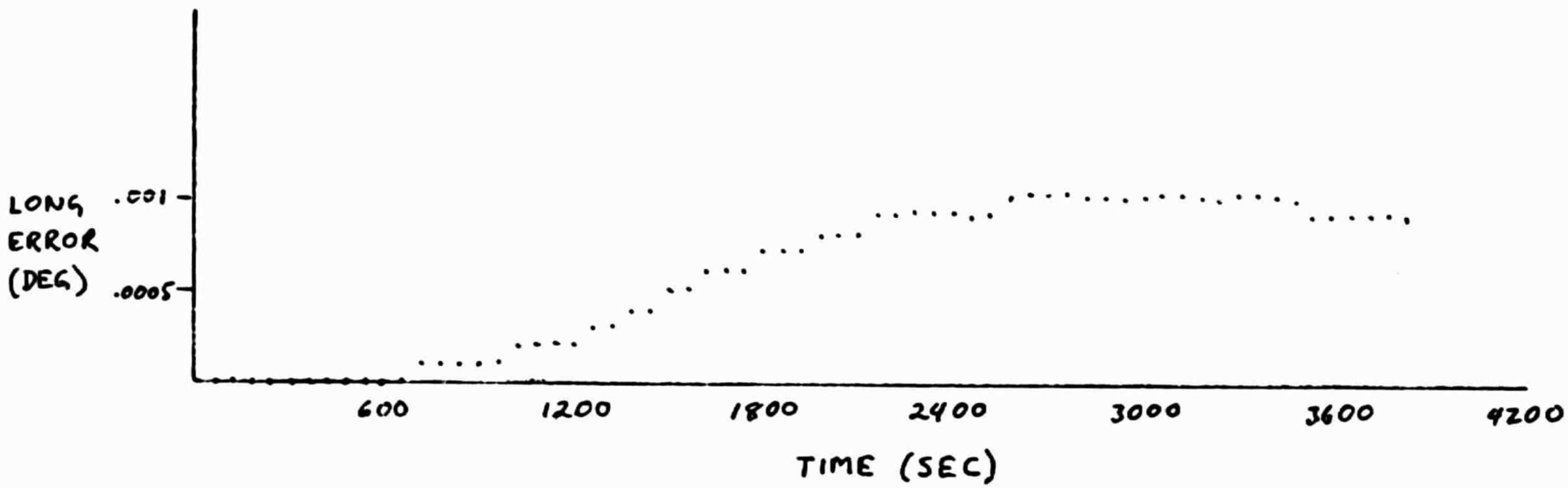


FIG. 3

DATE: 9-19-74
TEST: STATIC NAV TEST, STRAPDOWN INACTIVE, IN LAB
DATA: LATITUDE ERROR VS TIME

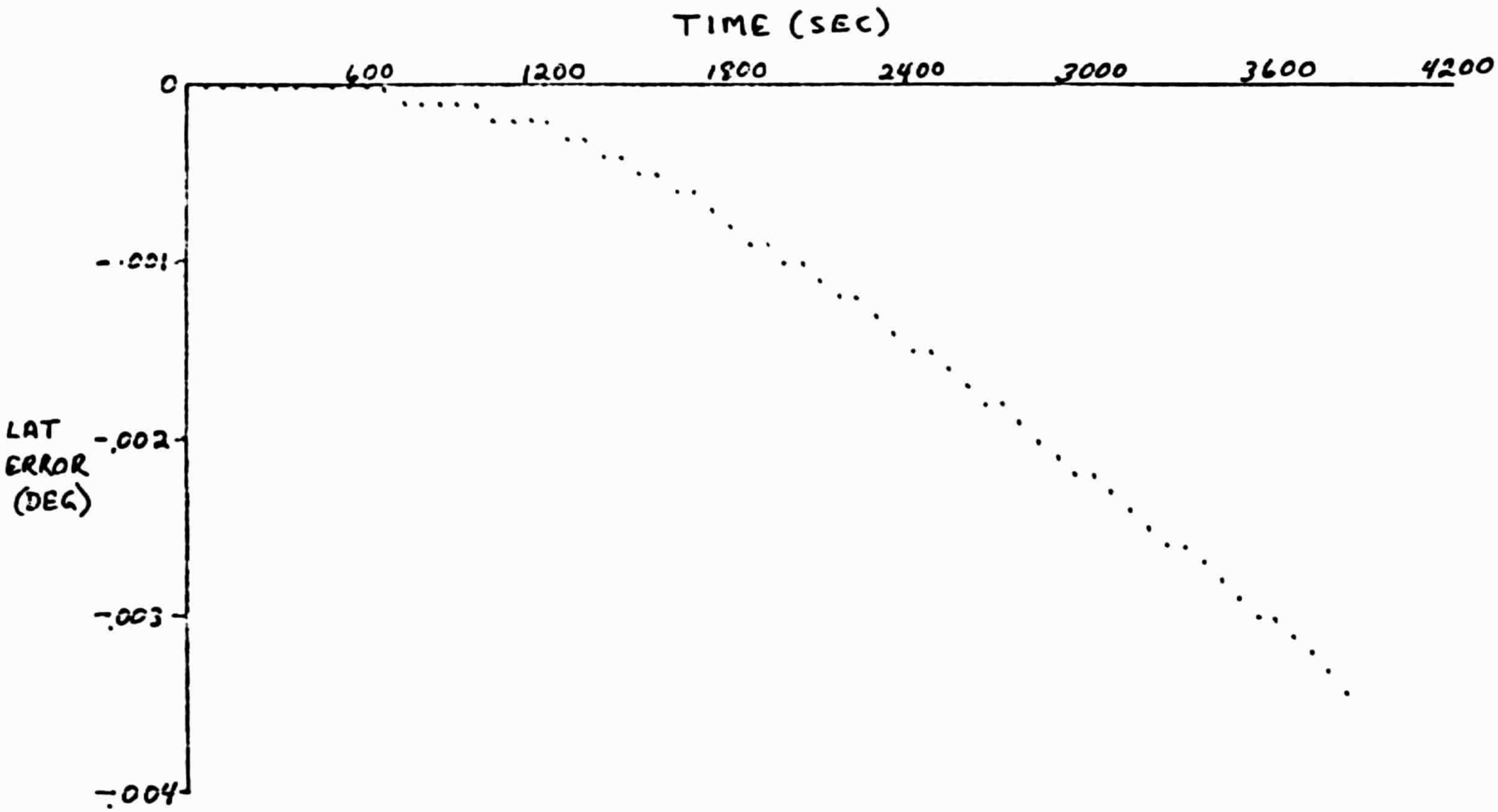


FIG. 4

DATE: 9-19-74
TEST: STATIC TEST, STRAPDOWN INACTIVE, IN LAB
DATA: TOTAL VELOCITY ERROR VS TIME

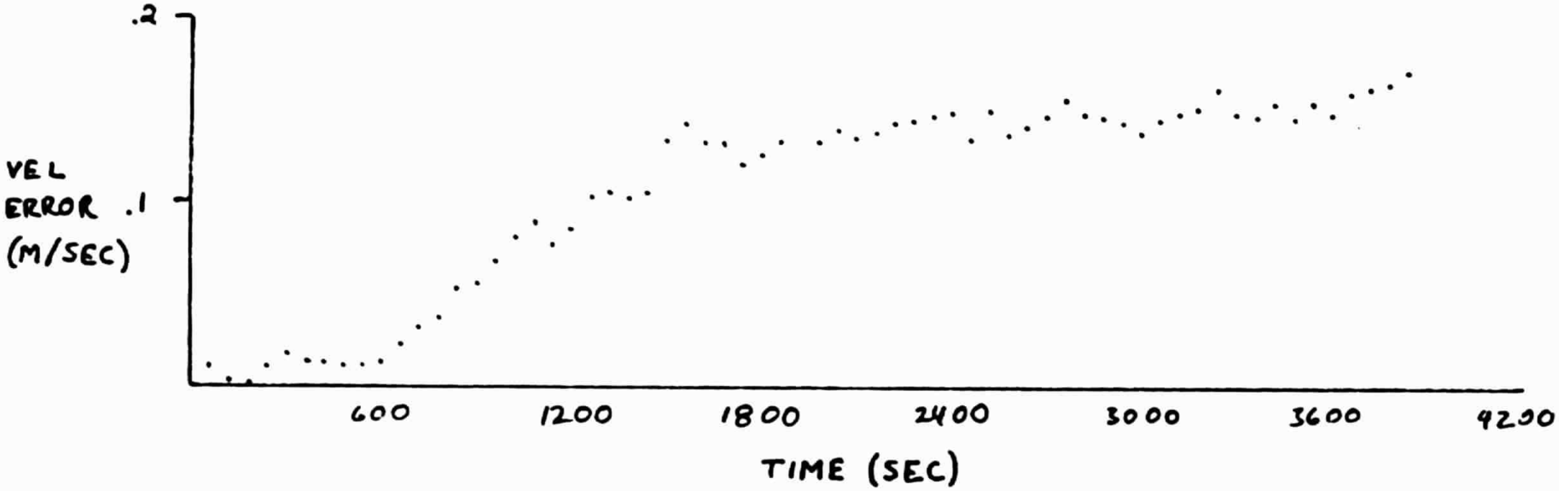


Fig. 5

DATE: 9-19-74
TEST: STATIC NAV. TEST, FULL SYSTEM ACTIVE, IN LAB.
DATA: LONGITUDE ERROR VS TIME

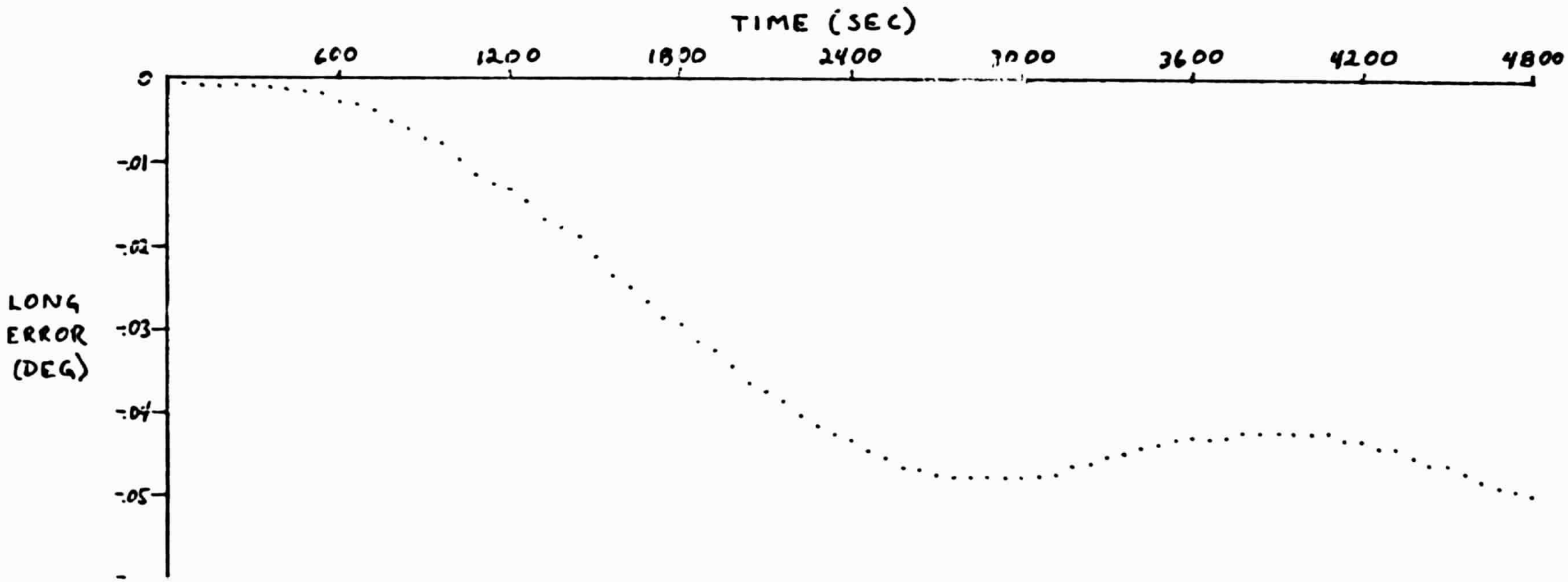


FIG. 6

DATE: 9-19-74
TEST: STATIC NAV. TEST, FULL SYSTEM ACTIVE, IN LAB
DATA: LATITUDE ERROR VS TIME

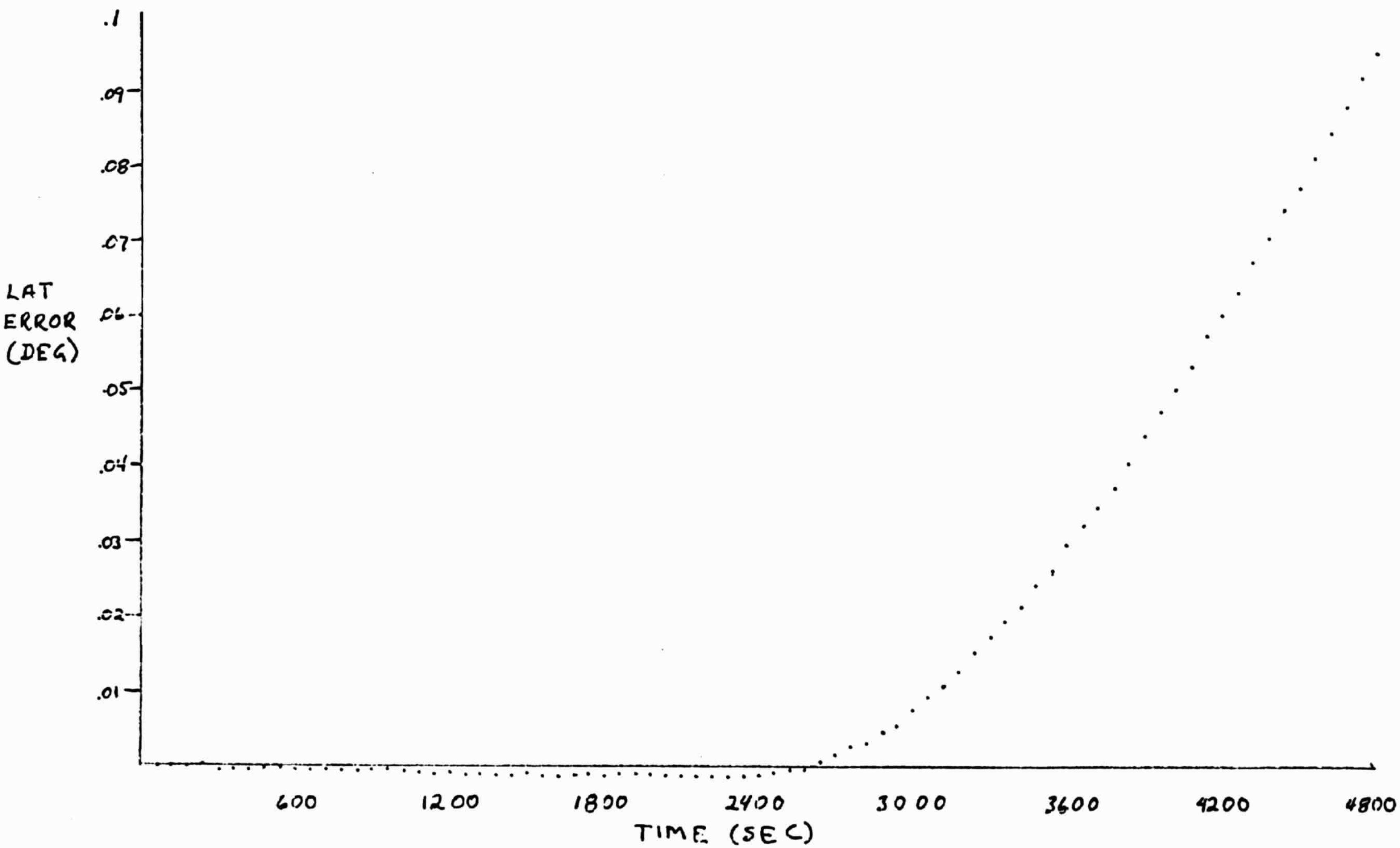


FIG. 7

DATE: 9-19-74
TEST: STATIC NAV. TEST, FULL SYSTEM ACTIVE, IN LAB.
DATA: VELOCITY ERROR VS TIME

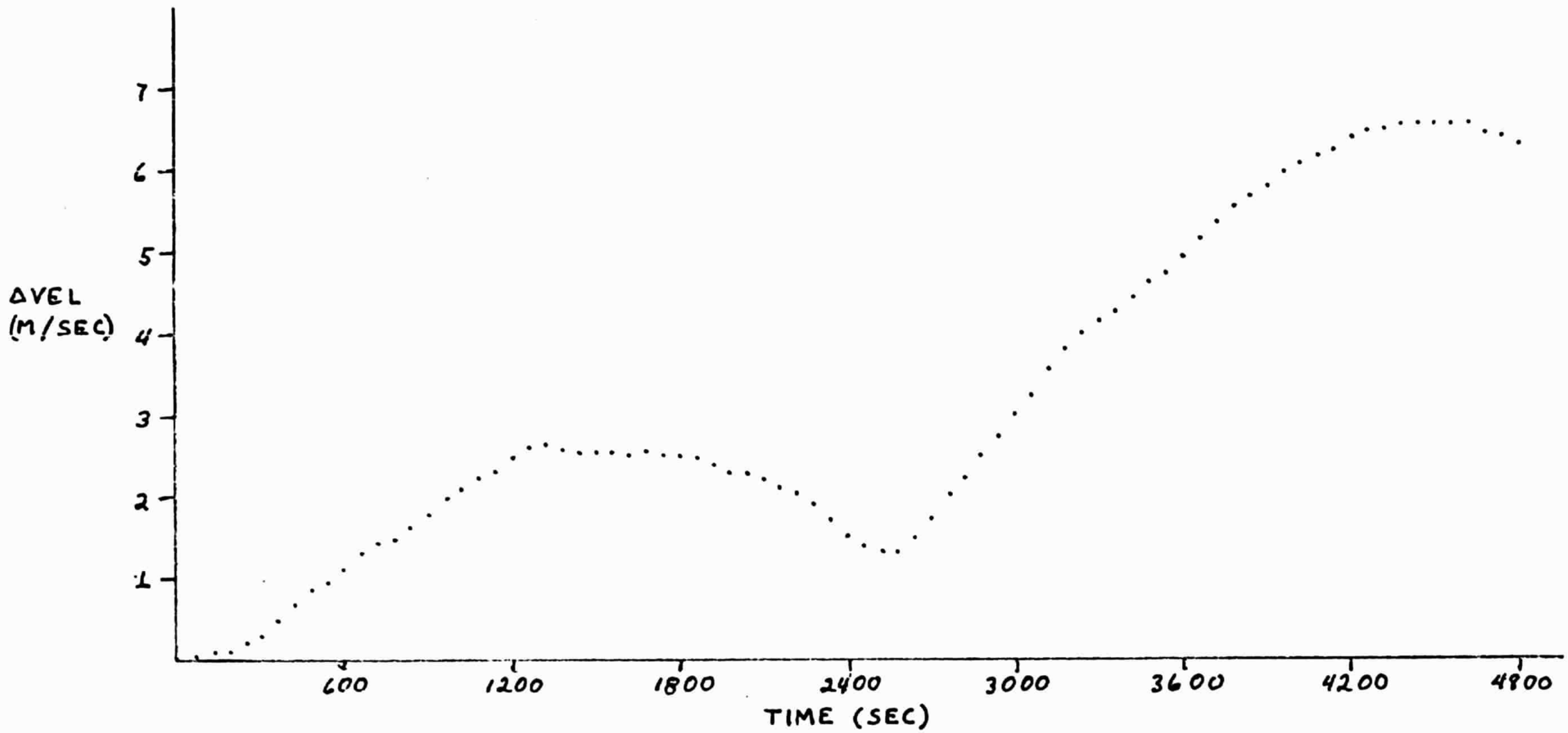


FIG. 8

Static test made with the full system active versus those in which the position computations were inactive did not indicate dramatic differences for the durations of these tests; however, it can be shown that velocity errors and latitude position errors do degrade the IMU strapdown reference.

System transmission line noise was observed in all three test environments. In a static mode, this noise was observed on the accelerometer inputs. Due to the low level of gyro input pulses in the static mode; it was difficult to detect gyro noise from the displays. Line receivers were added to the input lines at the computer; however, system transmission line noise was still observed (no line drivers were added at the signal processor end of the transmission line). In the test at Langley, it was found that system noise was less when the break-out box was installed in the transmission lines; there is, however, no guarantee that all noise was filtered out by this method.

Indications of large bursts of noise on one or more of the gyro channels was also observed in all test environments. In most cases, these would cause loss of strapdown reference but the noise source would then disappear; that is, the attitude of the strapdown would change by a large amount then would stabilize at that offset.

In a couple of cases, the noise source would remain, and once was traced to the loss of coarse bias in the Z gyro signal processor. It is felt that a lower magnitude noise, of this type, may have caused navigation errors without degrading the strapdown reference to a point that it could be detected by looking at the altitude displays in a non-static environment. These gross losses of altitude reference tended to occur when the system was in a high rate or high vibration environment.

In analyzing the mobile test unit and helicopter flight test, it can be observed that the rate of error build-up while in the static portion of the test is less than when the system is in a mobile environment (Figures 9 & 10). This condition can be due to anyone of, or a combination of the following:

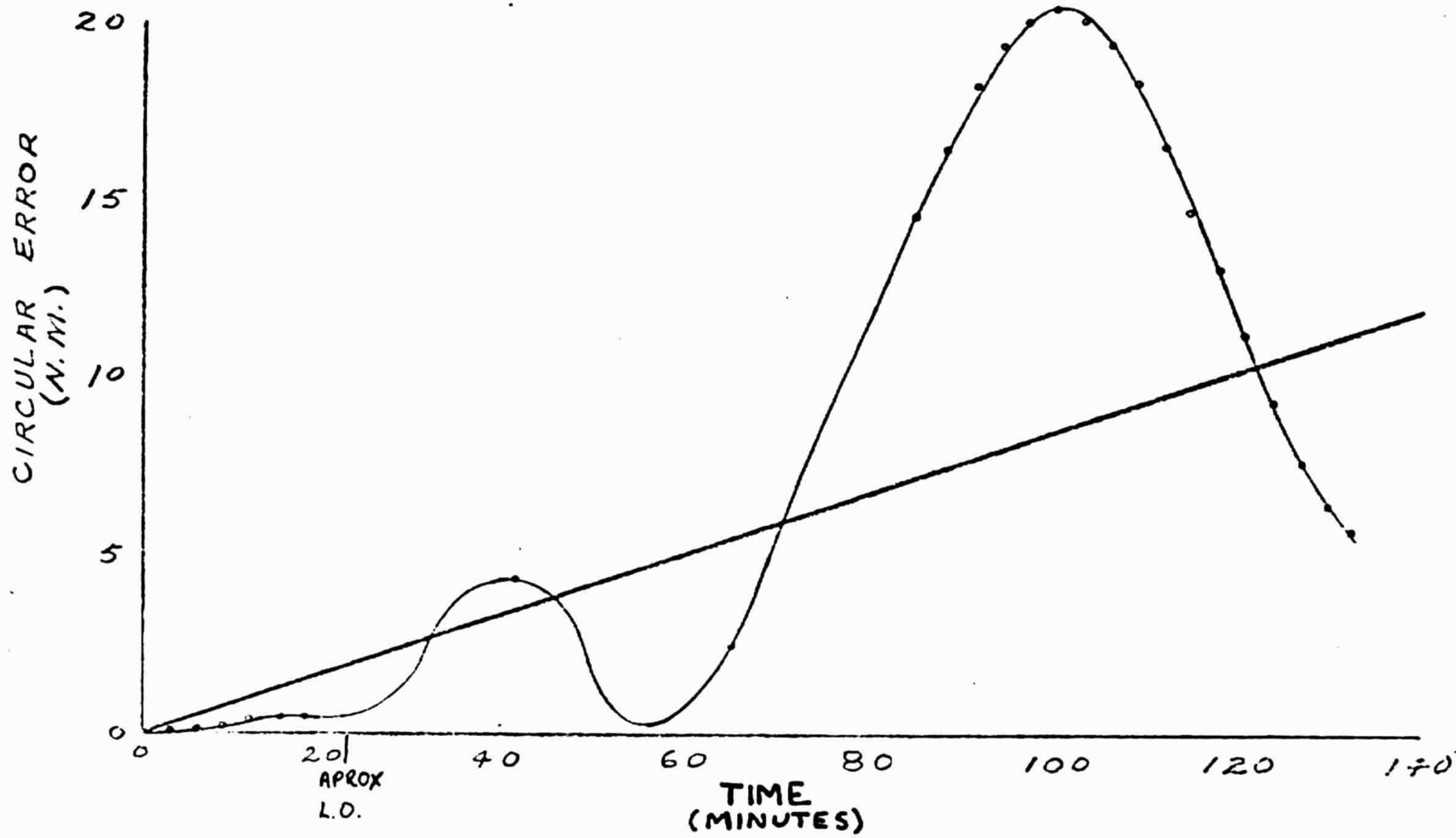
- Vibration - The vibration in the mobile environment could cause system noise to be at a higher level.

- Scale Factor vs. Constant Bias - The calibration program assumes that the day to day non-repeatability of the scale factor is low and that differences between calibration reading is due to changes in the constant bias; therefore, the scale factors computed in the lab were used for both the mobile test unit and helicopter test. If the scale factor on one or more of the sensors (accelerometer or gyros) significantly change, navigation errors of this type would occur.

- Sensor Misalignment Error - The sensor misalignments were determined in the lab; if any of these terms was in error, the calibration program would assume any bias due to this error would be due to the constant bias. In high rate or high "g" environments, this could cause navigation error buildups.

- Gyro or Accelerometer Bias Instability - If the constant bias on the gyros or accelerometers were to change from the time the calibration runs were made, the navigation errors would tend to build up (this error would occur in both static and mobile modes). The repeatability of the accelerometer and gyro bias was checked by running several calibration runs during the same day. The tests indicated better repeat on some sensors than on others.

LASER GYRO NAV. SYSTEM
CHECKOUT FLIGHT
2/14/75



FLIGHT NO. 1

Fig. 9

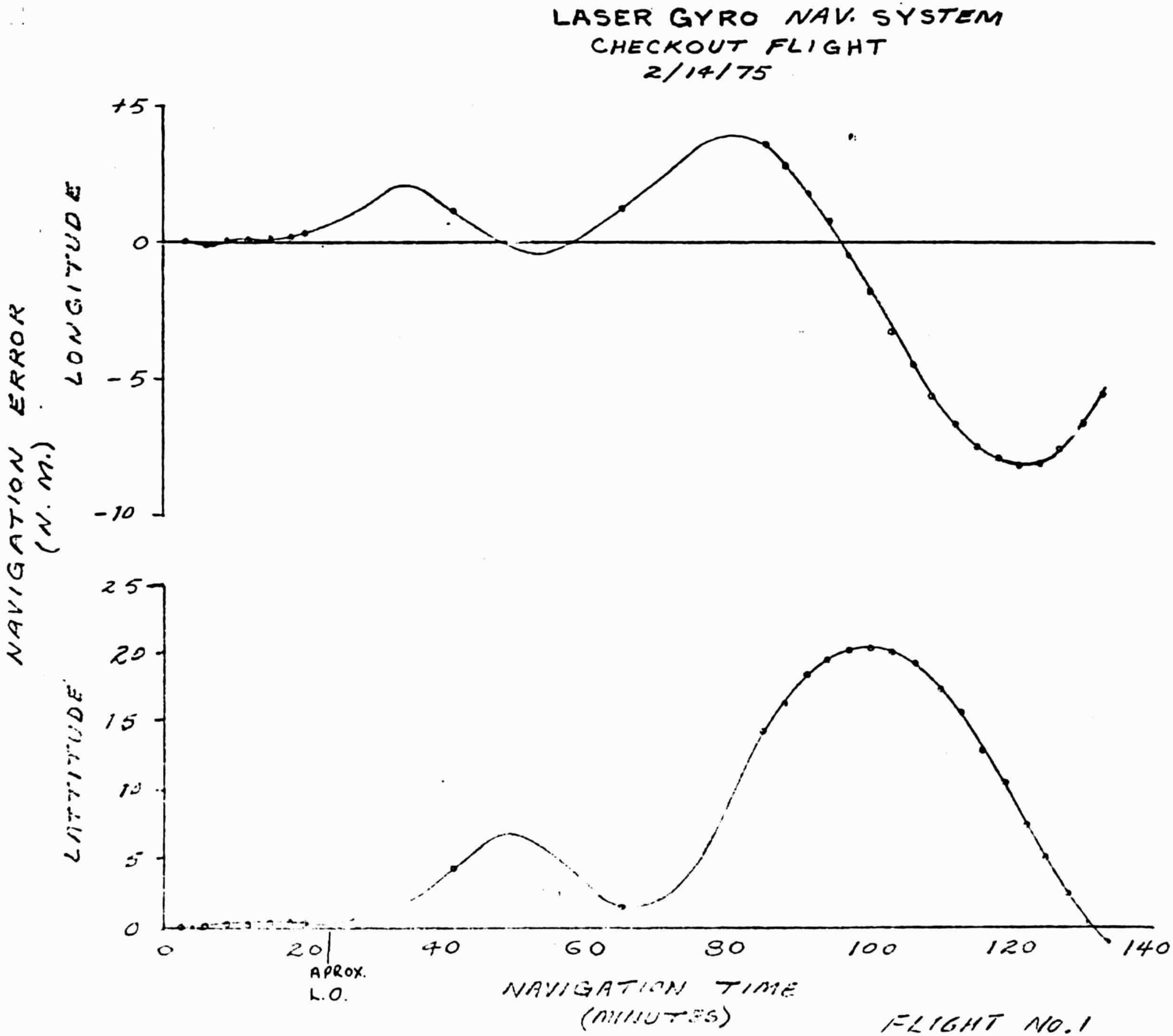

LASER GYRO NAV. SYSTEM
CHECKOUT FLIGHT
2/14/75
NAVIGATION ERROR
(N. M.)
LONGITUDE
+5
0
-5
-10
25
20
15
10
5
0
0
20
40
60
80
100
120
140
APROX.
L.O.
NAVIGATION TIME
(MINUTES)
FLIGHT NO. 1

FIG. 10

- Temperature Transients - The bias on the gyros is a function of the operating temperature. This operating temperature is maintained by a fan pulling air across the units. During one test at Langley, the navigation error build-up began when the IMU was exposed to cold outside air.

- Power Transients - In a test run at Langley April 4, 1975, a large error build-up began at the time power was transferred from the mobile power unit to helicopter internal power and on April 14, 1975, the transients at power transfer was significant enough to cause a computer memory loss. It is also felt that transients of switching from generator power to battery power may have caused some errors in the IMU outputs (fan speed change was noted upon switching from battery to ground power).

During flight test at Langley and Wallops, optical alignment leveling errors occurred when the wind was high. Leveling jacks were placed under the helicopter which increased the stability; however, significant error still existed. These errors caused significant navigation errors.

The effects of centripedal acceleration on the accelerometers was investigated. It was determined that due to the symmetry and close proximity of the accelerometers to each other, no significant error build-up is caused by unbalanced centripedal acceleration.

5.0 RECOMMENDATIONS

The following recommendations are made as means of reducing system error.

The addition of a gyro compassing alignment program into the navigation program would allow the system level alignment errors to be reduced even when the vehicle level stability is being disturbed by winds, sunlight or crews movement. The computer may not, however, have sufficient memory to hold the alignment program and navigation program at the same time. A

deletion of certain areas of the navigation program and a reduction in the size of the alignment program may be required.

The addition of line drivers at the signal processor end of the transmission line should reduce transmission line noise. These drivers should be compatible with the line receivers located in the computer. All six channels (3 gyro and 3 accelerometer) should have drivers and receivers.

Temperature stability of the air around the IMU should reduce the effects on the gyro bias.

Extensive lab testing should be made to determine sensor misalignments, biases and scale factors. Also, the stability and repeatability of scale factors and biases should be determined.

The source of large noise inputs should be isolated and eliminated.

The power source should be stabilized to prevent transients during power transfer. The IMU should be calibrated on the same power supply that the navigation is to be tested and all batteries should be at full power.